# No-Till Wheat and Barley Production in California

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**Authors:** G.S.Pettygrove, Extension Specialist, Department of Land, Air and Water Resources, University of California, Davis; M.J. Smith, Farm Advisor, San Luis Obispo; T.E. Kearney, Farm Advisor, Yolo Co.; L.F. Jackson, Extension Specialist, Department of Agronomy and Range Science, University of California, Davis; D.J. Munier, Farm Advisor, S.D. Wright, Farm Advisor, W.F. Richardson, Farm Advisor, P. Livingston, Staff Research Associate, K. Klonsky, Extension Specialist, Department of Agricultural Economics, University of California, Davis; S.K. Upadhyaya, Professor, Department of Biological and Agricultural Engineering, University of California, Davis; W. Bunter, Natural Resources Conservation Service, USDA.

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# Introduction

Soil erosion by water or wind is a serious problem on approximately one million acres of land in California's hills and valleys traditionally used for production of barley and wheat. Exposure of tilled soil on sloping ground can result in erosion and lead to loss of productivity and transport of sediment into streams and lakes even where total annual rainfall is very low. Although there are several options available to farmers for protecting soil from erosion, nationally, farmers have chosen methods that use crop residue management on approximately 75 percent of the acres covered by conservation compliance plans. Crop residue management methods include several types of conservation tillage, including no-till.

In California, many small grain producers use minimum tillage, reducing the number of tillage operations, adjusting chisels, discs, and cultivators to leave sufficient crop residue levels to qualify as conservation tillage according to USDA definitions. A small number of grain farmers are using no-till.

In no-till farming, as the name implies, tillage for seedbed preparation and weed control is avoided entirely. The only mechanical disturbance to soil is in a narrow slot or strip made by the planter or by fertilizer knives. Weeds are controlled with herbicide applications instead of with tillage. Potential advantages of no-till -- besides a reduction in soil erosion -- are a reduction in use of fuel (due to less cultivation) and increased capture of runoff due to improvement in tilth of the soil surface. No-till farming requires an increased use of herbicides and the use of a heavy no-till drill capable of penetrating untilled soil. No-till drills, due to the extra weight and strength of construction, are more expensive to purchase and operate than conventional planters.

No-till farming of dryland small grain has been tried by many farmers, but many questions about it remain to be answered. Tests of no-till farming conducted during the late 1980s and early 1990s were limited by severe drought. Long-term experiments in other locations show that several years are required to evaluate effects on soil tilth, crop disease, water use efficiency and fertility. Lacking long-term studies in California, we have to make educated guesses based on research done elsewhere.

The purpose of this bulletin is to provide ranchers and others interested in no-till small grain production with a discussion of production techniques, risks, and benefits.

# Conservation Tillage Definitions and Types of Systems

## Definitions

**Crop Residue Management (CRM)** is a year-round system beginning with the selection of crops that produce sufficient quantities of residue and may include limited secondary harvest of residue. It includes the use of a cover crop where sufficient quantities of residue are not produced. CRM includes all field operations that affect residue amounts, orientation and distribution throughout the period requiring protection. Site specific residue cover amounts needed are usually expressed in percentage but may also be in pounds.

**Conservation Tillage --** Any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water; or where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small grain residue equivalent on the surface during the critical wind erosion period.

## Types of Conservation Tillage

1. **No-till --** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

2. **Ridge-till --** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

3. **Mulch-till --** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with herbicides and/or cultivation.

**Other Tillage Types --** Tillage and planting systems that may meet erosion control goals with or without other supporting conservation practices (i.e., strip cropping, contouring, terracing, etc.).

4. **15-30% Residue --** Tillage types that leave 15-30% residue cover after planting or 500 to 1,000 pounds of small grain residue equivalent during the critical wind erosion period.

5. **Less that 15% Residue --** Tillage types that leave less than 15% residue cover after planting, or less than 500 pounds of small grain residue equivalent during the critical wind erosion period.

(Source: *National Crop Residue Management Survey, 1993*. Conservation Technology Information Center, West Lafayette, IN)

# No-Till Cultural Practices

Due to differences in climate, soil, expected yield, and conservation requirements, cultural practices vary among California's dryland small grain growers. But because there are only a small number of cultural operations, differences are minor. Recommended cultural practices for small grains are described in two publications: *UC IPM Small Grain Pest Management Guidelines* and *Integrated Pest Management for Small Grains* (Publications 3339 and 3333, University of California Div. of Agric. and Nat. Resources, Oakland).

The goal of no-till production is to maintain at least 30% residue cover on the surface of the soil, which is a USDA conservation compliance requirement for farming on highly erodible land. This is a challenge in California where small grain harvest residues are sometimes small in volume due to the arid climate and where post harvest stubble has traditionally been grazed by cattle or sheep.

In the sections below, the following components of no-till production are discussed:

_ Selection of an appropriate rotation
_ Production and protection of residue to provide soil cover
_ Use of herbicides instead of tillage to control weeds during fallow
_ Use of a planter capable of planting in untilled soil with minimal disturbance to residues
_ Provision of required nutrients to the crop without disturbing residue cover.

## Selection of Rotation

The choice of rotation -- whether to fallow fields between grain plantings, to plant wheat or barley two or more years in a row, or to rotate with safflower, a forage, or some other crop -- depends on many factors. Perhaps the most important factor is moisture availability which depends on rainfall and root zone waterholding capacity. Other factors include: Potential weed and disease control benefits afforded by rotation; equipment and labor availability; and the economic value of alternative crops such as volunteer or improved pasture, hay, or safflower.

In general, the adoption of no-till farming procedures should not greatly influence the choice of rotation. However, some no-till growers believe that in no-tilled fields, due to improved infiltration and reduced run-off, enough moisture is stored in the root zone that back-to-back cropping becomes possible where under conventional tillage, a moisture-conserving fallow was necessary. Moisture availability aside, two potential advantages of reducing the frequency of fallow are (1) greater production of crop residues (2) production of income every year. The traditional grain-fallow system in California does not produce very much organic matter.

Depending on how important fallow season moisture storage is, in the non-grain year(s), growers may (1) produce a different crop such as safflower, (2) allow resident vegetation to grow in the fall and winter for grazing, or (3) practice a clean fallow. If a no-till planter is available for both small grain and the alternative crops, no-till is possible in all three situations. A common rotation in the dryland areas of the lower Sacramento Valley is small grain in year 1, grazing of volunteer vegetation in year 2, and volunteer grazing/summer fallow in year 3. If this rotation were used in a no-till system, the main changes from conventional tillage would be (1) to prevent livestock from removing too much residue (2) to fallow the ground with a non-selective herbicide during the late winter and spring of year 3 to conserve moisture and reduce weed seed production.

No-till growers in the Sacramento Valley have also practiced a two-year (grain - volunteer/chemfallow) rotation. This has the potential to produce more organic matter and possibly even out income and risk.

There is some interest in a winter cereal-annual medic (*Medicago* spp.) rotation -- the Australian ley system. Annual medics such as bur medic or barrel medic produce a large percentage of hard seed. If the seed is protected from grazing and lightly tilled into the soil, a portion of the seed will germinate each year. This might provide for a higher legume component in the volunteer forage produced in the non-grain year.

## Residue Management: Effects of Tillage and Livestock

No-tilling requires a change from thinking of residue as cattle feed. The stubble should not be baled or heavily grazed. In rotations with one crop every two years, harvest residue must protect the soil against erosion during two consecutive rainy seasons. Fields selected for no-till production should be relatively free of weeds, vertebrate pests, and areas with ruts and compaction.

Conversion of a field to no-till begins with the harvest of a crop that produces enough residue to protect the soil and meet the 30% post-plant residue cover requirement. Harvest residue from small grains (chaff and straw) should be distributed as evenly as possible to prevent heavy straw rows from affecting stand uniformity of the next crop.

Table 1 displays the approximate percentage of residue cover remaining on the soil surface after a single pass of different tillage and management operations based on five years of field studies conducted in the Montezuma Hills (Solano Co.) and the Dunnigan Hills (Yolo Co.). Practices are not listed in any particular sequence. Choose the appropriate practices for your operation. The values shown should be viewed as averages. Actual effects on residue cover will vary with speed of operation, soil moisture, how the implement is set, and other factors.

**Table 1. Effect of tillage, grazing, and weather on small grain residue surface cover.**

| Tillage/Management Operation (1X) | Percent of Residue Remaining |
|---|---|
| Immediate post-harvest | 85 |
| Moldboard plow, slatted | 15 |
| Moldboard plow (6-8") | 5 |
| Knifed fertilizer | 70 |
| Disc (3 " depth control) | 70 |
| Field cultivator (3") | 80 |
| Stubble disc (3") | 50 |
| Sheep grazing | varies |
| Chisel (12") | 75 |
| Chisel plow (4-5" points | 65 |
| Light harrow | 90 |
| Winter weathering | 90 |
| Heavy harrow | 80 |
| Planting (drill) | 90 |

Source: *Residue Management Guide for Dryland Grain* (USDA SCS, Davis, CA. October, 1991)

Sample calculation: Assume that immediately after harvest, residue cover is 85%. What is the percent cover after stubble discing (1X), heavy harrowing (1X), field cultivator (1X), and drill seeding? Answer: 0.85 x 0.50 x 0.80 x 0.90 = 0.306 or about 30%

## Measuring Residue

The values in Table 1 are for planning purposes. To measure actual residue coverage, growers should use the line-transect method. This is also called the knotted rope method, but any line with regularly spaced marks on it, such as a measuring tape, can be used.

**Step one:** Following planting or any time a residue cover measurement is desired, select an area in the field that is representative of the whole field. Avoid washed out gullies or areas affected by flooding or planting skips.

**Step two:** Lay out a 100- or 50-ft tape or line diagonally to the direction of planting or harvest residue rows in the field. This will give you a more accurate reading than following rows. The tape or line you use should be clearly marked at regular intervals.

**Step three:** Anchor both ends of the line.

**Step four:** Walk along the line or tape and look straight down at each recording point (for example, the foot marks on a measuring tape). Record the number of points where the mark is directly above a piece of residue. Avoid moving the tape while counting; always count from the same side of the tape mark; look straight down -- imagine a small drop of water falling from the point of reference. If it would fall on plant residue, count it as a "hit".

**Step five:** The total number of intersections or "hits" you observed, if expressed as a percentage of the total number of spots observed, will equal the percentage of ground surface covered by residue. Using a 50-ft tape: If residue was observed at or directly below 35 of the foot interval marks, then residue cover equals 70%.

**Step six:** Repeat the process at three to five random locations in the field and average the results to arrive at an estimate of residue cover for the entire field.

In counting "hits", there will be some judgement calls. To help decide if the residue should be counted, remember that a piece of residue must be large enough to dissipate the energy of a raindrop during an intense storm. To be counted, the residue must be larger than 3/32 inches in width. Use a 3/32-inch diameter wooden dowel rod or brazing rod to represent such a dot when you are in the field. Don't count the residue if it is too small or fails to intersect the mark. (Source: *Conservation Impact*, newsletter of the Conservation Technology Information Center, West Lafayette, IN, Vol 13, No. 2, February 1995)

**Measuring Residue for Assessment of Wind Erodibility:** On highly erodible land where the main cause of erosion is wind, conservation tillage systems should maintain at least 1,000 lb/acre of flat small grain residue or its equivalent on the surface of the soil during critical wind erosion periods. To measure this, residue can be collected from several representative small areas and weighed. Where the residue or plant present is anything other than flat small grain residue (FSGR), the amount present must be converted to FSGR. NRCS offices can provide conversion graphs. To cite one example: For "standing small grain stubble on a flat surface", approximately 500 lb/acre is considered to provide protection equivalent to 1,000 lb/acre of FSGR.

## Weed Management

In a no-till production system, without the benefit of tillage, weed control is accomplished exclusively through use of herbicides. Because mechanical control is not an option under no-till, it is important to begin no-till in fields that are free of difficult-to-control weeds and to follow a program of herbicide use during any fallow period. Although there are no weed species specifically a problem under no-till, converting to a no-till production system can have profound effects on weed species mix. Because the surface of the soil is not disturbed as much in a no-till system, perennial species may have a better chance of becoming established, particularly where annual cropping is practiced. On the other hand, annual species like wild oats, the seeds of which are buried by primary tillage and then returned to the surface by subsequent tillage, may decrease in number under no-till.

Control of weeds from late winter through early fall prior to planting the crop is important not only for moisture conservation, but to keep weeds from going to seed and to prevent perennials from becoming established. Growers should not allow noxious weeds such as ripgut brome (*Bromus diandrus*), downy brome (*Bromus tectorus*) or rattail or Zorro fescue (*Vulpia myorus*) to go to seed. Properly managed, livestock grazing can help suppress some weeds such as yellow starthistle (*Centaurea solstitialis*), but grazing cannot replace use of herbicides. The most serious of the perennial weeds in no-till cereal grain production are field bindweed (*Convolvulus arvensis* L.), Russian knapweed (*Acroptilon repens*), and, in some areas, Johnsongrass (*Sorghum vulgare*).

Where a fallow period is practiced, weed control during the fallow is accomplished by using herbicides in a so-called "chem-fallow". In low-rainfall regions, an additional benefit of chem-fallowing is the storage of moisture in the root zone that would otherwise be consumed by weeds.

A single application of herbicide often costs several dollars per acre more than a single field cultivation; therefore the cost of weed control could be higher in a no-till system. However, the number of applications of herbicide and weed control tillage operations is influenced by several factors, and it should not be assumed that the same number of operations will be required in the two systems or that a straightforward cost comparison can be made.

An example of chem-fallow might be as follows: 0.75 to 1.5 pints/acre each of Roundup® and 2,4-D in late winter or early spring, followed by a second similar application in late spring to kill any summer weeds, then no further applications until the subsequent crop is established. If significant rainfall occurs prior to planting, a third application may be necessary. Depending on soil type, no-till fields may be firmer under wet conditions than tilled fields so that herbicide can be applied in situations where cultivation would not be possible.

Under annual cropping rotations, it is common to wait until after the first germinating rains occur in the fall before making an application of Roundup® plus 2,4-D to achieve pre-plant weed control. When germinating rains are late, it may be necessary to start planting when the soil is still dry and weeds have not yet germinated.

Control of weeds during the cropping period is also of major importance for both no-till and conventional tillage plantings. Weed control practices will generally be the same in the two systems. An exception is that when planting no-till into dry soil, it is especially critical to closely monitor emergence of crop and weeds. Some weeds, such as downy brome may out-compete the grain crop if they emerge within ten days of planting.

## Selecting a No-Till Planter

There are two common types of planters considered suitable for reduced tillage planting: Those employing disc openers and those using hoe openers. Both types have been used in no-till small grain plantings in California, but disc drills are the most common. On both types of planter, seed may be distributed to the openers with a conventional fluted meter or an air-seeder. The following information is obtained mainly from a North Dakota extension bulletin (Hauck and Fanning, 1984). Due to higher soil organic matter levels and the annual freeze-thaw cycle, soils in North Dakota are generally more friable (have better structure) than soils in California, so information presented here should be used with caution.

Compared to conventional drills, no-till disc drills are heavier built and have improved trash clearance. Openers are independently mounted units designed to cut through residues for seeding. Spring loaded or hydraulically controlled openers are built to apply as much as 400 lb of down-pressure per opener. Usually, openers are staggered to aid in trash handling. Double discs may be offset and may include some type of seed tube and scraper. A coulter to cut through residue and provide a seed opening is often mounted in front of the disc openers (Figures 1-3).

**Fig. 1. A cutting coulter is added ahead of a double disc opener to cut through residue and provide a seed opening (Hauck and Fanning, 1984).**

**Fig. 2. A double disc opener with a leading disc**

**to provide residue cutting similar to a single disc (Hauck and Fanning, 1984).**

**Fig. 3. A single disc opener with a seed tube shoe-scraper (Hauck and Fanning, 1984).**

While disc drills are designed to cut through residue, air seeders and hoe drills are designed to lift or push it aside (Fig. 4). Hoe type planters will disturb residue more than no-till disc drills.

**Fig. 4. Shovel openers have an advantage over disc openers when moisture is several inches deep. Dry soil is rolled aside placing the seed into moisture without burying it too deep (Hauck and Fanning, 1984).**

Air seeders blow seed laterally under the

➢**Opener design, press wheels, and coulters**: Is down-pressure independently controlled on individual openers? Can the planter operate under variable moisture conditions? How is mud and trash build-up prevented? When it is adjusted to penetrate hard soil, will it sink into the ground or "dig a ditch" when it hits a soft spot? Is depth controlled by press wheels? See Fig. 5. Is it easy to change press wheels or lift them out of the way for changing conditions? Does the opener clear chaff from the seed row? Does it "hairpin" straw into the planting groove?

wings of a shovel opener. Air seeders mounted on chisel plow frames have a greater trash capacity than those mounted on field cultivator frames or hoe drills.

A list of names, addresses, and telephone numbers for suppliers of no-till planters is available from: *No-Till Equipment Survey, P.O. Box 624, Brookfield, WI 53008-0624.*

In several locations in California, no-till custom planting services are available. Anyone considering buying or leasing a no-till planter should consider the following design and operating features:

➢**Weight and pulling force:** Will your tractor be able to pull a fully loaded drill uphill under variable soil moisture and residue conditions?

➢**Planting speed**: What width of drill is available and at what speed will it operate under your conditions?

➢**Down-pressure on openers**: Will this be adequate to penetrate dry soil under your conditions? A wider row spacing (fewer openers for the same drill width) will result in more down-pressure per opener. Consider row spacings greater than the conventional 6-7 inches. Greater row spacings -- up to 12 inches -- may be more suited to drier conditions and where weed pressures are not too great. Paired row spacings (for example, each row is 6 inches from one row and 10 inches from the other) are available on some planters. Not enough testing has been done in California to state whether there are advantages or disadvantages to this configuration.

**Fig. 5. On most no-till disc drills the furrow**

**opener and the press wheel are mounted on the same run to maintain depth control (Hauck and Fanning, 1984)**.

There are many different designs of press wheels. A lightly loaded flat-surface wheel will pick up and carry both mud and straw. Steel wheels also have a greater tendency to cause soil sticking than do rubber treads, but scrapers on steel wheels help overcome the problem. Press wheels should match the amount of soil moved. Narrow wheels are more desirable if the no-till drill is operated at greater than 5 mph.

Coulters placed ahead of openers have been shown to improve planter performance by enhancing residue flow (Fig. 5). Heavy chaff rows will detract from the performance of furrow openers. Openers that clear the seed row of residue have shown a yield advantage in heavy stubble residue. (Payton, Hyde, and Simpson, 1985).

➢**Fertilizer application**: Can fertilizer be placed away from the seed thus allowing higher rates of N to be used? Can both dry and liquid materials be applied?

➢**Other**: How often will press wheels, openers, and fertilizer knives have to be resurfaced or replaced? Can the drill be pulled on a highway behind a pick-up? Is it too heavy to load onto your equipment trailer?

## Fertilization in No-Till Systems

**General nutrient requirements**: Dryland small grains in California frequently respond to N fertilization. Generally, 40 to 80 lb/acre of N is required, with seasonal rainfall being the key determinant within that range. In the drier areas of the state where expected yields are low, it is possible to apply sufficient N with the starter fertilizer that is commonly drilled with the seed. Where a larger amount of N is needed, straight N fertilizers are applied preplant or as mid-season topdressing. P responses are obtained consistently in some soils. S, Zn, and K responses are unusual but have been observed. Soil testing is recommended for determining the need for P, K, and Zn (*Soil and Plant Tissue Testing in California*, U.C. Div. of Agric. and Nat. Resources, Bulletin 1879).

Following is a short discussion of several aspects of nutrient management under no-till.

**Soil sampling:** Under no-till conditions, immobile nutrients will accumulate in portions of the soil profile. Conventional sampling to a depth of 6 to 8 inches is adequate, but where there has been continuous no-till for several years, an additional sample from the 0-4 inch depth may reveal nutrient translocation by the crop to the surface layer.

**N requirement under no-till:** Field research in some parts of the US has shown that the N requirement may be slightly higher under no-till than conventional tillage systems. Tillage stimulates decomposition of crop residues due to the increased exposure of soil to oxygen and the more thorough mixing that occurs with tillage. When tillage is reduced in frequency, organic matter content of the soil will increase. With slower organic matter decomposition, less nitrate is produced. N fertilizer requirement in no-till small grain has not been studied in California. If the required rate is higher, it is probably only a small increase, perhaps 10-15 lb N/acre.

**Fertilizer placement in no-till systems:** Both N and P fertilizers should be placed in sub-surface bands rather than be broadcast on the surface. This is good advice regardless of the tillage system, but it is especially true for no-till. Plant residues present on the surface of the soil in a no-till system will immobilize inorganic forms of N (due to microbial activity). Where urea fertilizers are applied, presence of residues may enhance loss of ammonia to the atmosphere. Also, in both no-till and conventional tillage cropping systems, surface broadcast application of N may stimulate weed growth.

Where only low rates of N and P are required, the fertilizer is almost always drilled with the seed in conventional tillage systems. This will also work in a no-till system, requiring only that the drill have a fertilizer attachment. What can be done where more N is required than the amount that can be applied with the seed? In conventional tillage systems, N (often in the form of aqua ammonia, anhydrous ammonia, urea-ammonium nitrate solution, or ammonium sulfate) is applied before planting in subsurface bands with a fertilizer ground applicator. In no-till fields this will not work, because the conventional fertilizer applicator will not penetrate the untilled soil and would disturb the residue too much.

Simply increasing the rate of N applied with the seed is not a good idea due to the increased risk of stand reduction. With diammonium phosphate, urea or other straight N fertilizers, it is not recommended that more than 25 or 30 lb N/acre be applied with the seed. Wet soil followed by drying will increase the risk (Hauck and Fanning, 1984).

In a no-till system, one solution to this problem is to apply N through separate applicator knives mounted on the planter. These knives should be set to place fertilizer 3 to 6 inches deep -- well below the depth where immobilization by crop residues occurs. This is sometimes referred to as "deep band" placement. In some no-till seeders, a deep-band fertilizer knife is positioned between each pair of seed openers (Fig. 6).

Some research shows that dual placement of fertilizer -- ammonium phosphate starter with the seed and deep-banded N fertilizer -- is ideal. Others have found no advantage to deep band placement (Deibert et al., 1985). Various placement combinations have been investigated in the Pacific Northwest (Veseth, 1985). This has not been studied under the conditions that prevail in California.

**Table 2. Wheat response to N topdressing (50 lb N/acre as urea) applied at jointing stage under no-till and conventional tillage conditions. (Yolo Co., 1987)**

| Rotation | No-till | Conv. till |
|---|---|---|
| | ----grain yield, lb/acre---- | |
| *Wheat after fallow* | | |
| Control | 1670 | 1661 |
| +Topdressing | 1670 | 1881 |
| %Residue cover | 87 | 5 |
| *Wheat after wheat* | | |
| Control | 1425 | 1479 |
| +Topdressing | 1398 | 1851 |

**Fig. 6. Several no-till seeders are designed for a total fertilization program during seeding. A separate row of openers is used to place N between the seed row (Hauck and Fanning, 1984).**

**Mid-season topdressing of N on no-till fields:** While dryland grain fields are not often topdressed, it is sometimes necessary where winter leaching has occured and where yield potential is high enough to justify the cost. Research conducted in California and elsewhere indicates that fertilizer N surface broadcast on fields with high levels of crop residues is not as effective as on low-residue ground (Table 2).

As described above, the reasons for this ineffectiveness are probably microbial immobilization of N in the residue layer and possibly increased ammonia volatilization loss.

One way to overcome this problem is to foliar fertilize with urea or urea-ammonium nitrate solutions. This is a relatively common practice in conventional irrigated grain fields.

**Use of dry bulk-blended fertilizers:** Bulk-blended fertilizer should be formulated with materials that match in particle size and shape in order to avoid segregation during loading, transport, and application. Segregation reportedly has been a problem with some air-seeders (Walker, 1983). Growers using bulk blended materials should check for uniformity during loading and application.

| | | |
|---|---|---|
| %Residue cover | 96 | 33 |

# Impact on Yield and Cost of Production

## Grain Yields

Few multi-year comparisons of no-tilled and conventionally tilled small grain have been conducted in California. Replicated strip trials in Yolo, San Luis Obispo, Tehama, and Tulare counties during the late 1980s and early 1990s were limited by drought and, in some cases, inadequate weed control. Grain yields are shown in Table 3.

At the Yolo Co. Rominger site shown in Table 3, yields in grain-fallow rotation were about the same under no-till and conventional tillage, averaging 1700 lb/acre during the period 1987-91. Both wild oats and ripgut brome provided severe competition to the grain. In some areas of the experiment, fall tillage on the conventionally tilled plots appeared to make the wild oats infestation worse than in the no-till plots. At other locations in Yolo Co. the experiments were conducted only for one year, so no conclusions can be drawn regarding the effects over time of no-tilling on soil, plant disease, and weed pressures.

## Cost of Production

Cost of small grain production in no-till and conventional tillage systems will be similar depending on the cost of planting in the two systems and the relative cost of tillage for weed control and seedbed preparation in the conventional system versus cost of fallowing with herbicide in the no-till system.

Examples of operating costs for two-year barley and wheat rotations are summarized in Tables 4 and 5 below. Costs shown are based on interviews with a small number of growers. In both the wheat and barley example, planting costs were higher in the no-till system due mainly to greater fuel use. In the wheat example (Table 5), hourly cost of planting with the no-till drill is nearly three times higher than in the conventional system, and planting is almost twice as slow. However, the no-till planting includes application of all fertilizer through the no-till drill, whereas some of the fertilizer in the conventional systems is applied in a separate operation.

In the barley example, fallow-period herbicide application was slightly less expensive than the total cost of tillage (chisel plowing, discing, and three field cultivations) in the conventional tillage system. In the wheat example, a single herbicide application in the no-till fallow was less expensive than the tillage required in the conventional tillage system. In some cases, two or three fallow-season herbicide applications would be required in no-till, making total operating costs of the two systems more nearly equal.

More detailed operating cost data are shown Appendix D.

**Table 3. No-till and conventional till small grain yields, 1987-91 U.C. on-farm experiments. At some locations, yields are averages for several fertilizer treatments. All sites were planted to wheat except where noted.**

| Site Location/Year | No-till | Conventional till |
|---|---|---|
| | ----------------lb/acre--------------- | |
| Yolo Co. - Rominger, wheat after fallow | | |
| 1987 | 1670 | 1661 |
| 1989 | 1789 | 1459 |
| 1991 | 1649 | 1980 |
| Yolo Co. -Rominger, wheat after wheat | | |
| 1987 | 1425 | 1479 |
| 1988 | 1544 | 2335 |
| 1990 | 1040 | 937 |
| 1991 | 2095 | 1860 |
| Yolo Co. - Hayes 1990 | 1796 | 1881 |
| Tehama Co. | | |
| 1987 | 1243 | 1203 |
| 1988 | 2016 | 2681 |
| Tulare Co. | | |
| 1987 | 2186 | 2176 |
| 1988 | 1435 | 1011 |
| San Luis Obispo Co. | | |
| Shandon 1988 (barley) | 1302 | 894 |
| Carrisa 1988 | 1193 | 1157 |

**Table 4. Example of operating costs for no-till and conventional till barley -- Central Coast 2-year grain-summer fallow rotation (derived from Klonsky et al., 1994a and 1994b).**

| No-till | $/acre | Conventional till | $/acre |
|---|---|---|---|
| Fallow - 2X herbicide application | 18 | Chisel plow, disc, cultivate 3X | 21 |
| Plant and fertilize | 38 | | 27 |
| Post-emerge herbicide application | 11 | | 13 |
| Pick-up truck use | 1 | | 1 |
| Harvest and haul[a] | 18 | | 18 |
| Interest on operating costs | 5 | | 4 |
| Total operating costs | $91 | | $85 |

[a]Based on grain yield of 1 ton/acre

**Table 5. Example of operating costs for no-till and conventional till wheat -- Sacramento Valley 2-year grain-summer fallow rotation (derived from Kearney et al., 1994a and 1994b).**

| No-till | $/acre | Conventional till | $/acre |
|---|---|---|---|
| Fallow herbicide application | 8 | Plow, disc 2X | 30 |
| Plant and fertilize | 52 | Fertilize | 22 |
| | | Plant | 26 |
| Post-emerge herbicide application | 33 | | 30 |
| Pick-up truck use | 4 | | 3 |
| Harvest and haul[a] | 18 | | 21 |
| Interest on operating costs | 5 | | 7 |
| Total operating costs | $120 | | $139 |

[a]Harvest and haul cost based on grain yields of 1 ton/acre for no-till and 1.5 ton/acre for conventional till reported by different growers.

# Other Benefits and Limitations of No-Till Farming

## Impacts on Soil Organic Matter

Reduced tillage systems affect the distribution of organic matter in the soil, increasing the organic matter and nitrogen content of the surface soil compared to conventional tillage. This is a result both of reduced contact of residues with soil microbes and a reduction in exposure of soil organic matter to oxygen. In one study, researchers measured 43% more total N in the top two inches of soil in untilled soil compared to conventionally tilled soil after six years of tillage differential (Gallaher and Ferrer, 1987). It is not known if such increases in surface layer organic matter occur under climatic conditions that prevail in California. Any such increase in organic matter would possibly increase infiltration and soil water-holding capacity (Eghball et al.,1994).

## Impact on Water Infiltration and Water-Holding Capacity

Even though no-till soils tend to develop higher bulk densities than conventionally tilled soils (Hammell, 1995), there will be more macropores (due to increased number of decayed root channels), and more organic matter. This will increase both infiltration rate and soil water-holding capacity. Whether this actually produces a significant benefit for grain production under California conditions is not known.

Some growers in California and elsewhere state that in no-tilled fields, they see less runoff and better water infiltration. Sprinkler infiltrometer tests conducted in side-by-side plots at the A.H. Rominger ranch in Yolo Co. showed that water ponded and ran off much sooner on dryland wheat plots that had been annually disced for four years than on plots that had been no-till farmed for an equal length of time (Table 6). The observed improvement in infiltration likely occured due to preservation of macropores and cracks in the soil that are disrupted by tillage under conventional tillage systems. Also, in the no-till plots, the higher residue level may have inhibited crusting that occurs under the impact of water droplets.

**Table 6. Amount of water applied to a clay soil on no-till and conventional-till plots before ponding and run-off occurred .**

| Water applic. rate | No-till | Conventional till |
|---|---|---|
| | ------inches of water applied -------- | |
| 2 in/hr | 2.07 | 0.48 |
| 4 in/hr | 0.53 | 0.25 |

Water was applied by sprinkler to a relatively dry soil on small, uncropped plots that had been in no-till or conventional-till for four years. A.H. Rominger & Sons, Winters, CA. April 1990. Data courtesy of T.L. Prichard.

Some no-till grain growers in California believe that in some years enough moisture has been stored in the soil profile due to decreased runoff that they can produce two crops in a row. How often this occurs and the magnitude of such a benefit has not been investigated in California. Studies in other locations show various possibilities. Long term field studies in eastern Oregon showed that the tillage pan that often develops in small grain production limits rooting depth and water storage. In another study in north central Oregon, summer seed-zone water loss was higher under no-till than either bare soil mold-board plowed or stubble mulch. Researchers attributed this to the enhanced upward movement of water through continuous capillary pores in the no-till during the summer. In the stubble mulch and plowed plots, water loss was less because of tillage disruption of pores -- thus providing a "dust mulch" (Schillinger and Bolton, 1993).

In another study conducted in North Dakota for five years, no-till and conventional till spring wheat consumed about the same amount of water during the growing season. Storage efficiency -- defined as the portion of total precipitation that is stored in the soil profile -- did not differ among tillage systems (Deibert et al, 1986). One should be cautious about extrapolating the results of these studies to California where due to climatic differences, the distribution of moisture and plant roots in time and space may be quite different than in Oregon or North Dakota.

## Disease and No-Till Practices

One concern about no-till farming is that crop residues left on the surface will increase carryover of disease organisms and/or make the soil more suitable for pathogens. In Washington, two of the main root diseases of wheat --take-all and *Pythium* root rot -- occurred more frequently or more severely on consecutive wheat crops seeded directly into the undisturbed stubble than on wheat seeded into plots that had been prepared by moldboard plowing or discing. The disease apparently was increased because of more infested debris and because the inoculum source was ideally positioned for infection of the crop (Moore and Cook, 1984; Veseth, 1984).

On the other hand, researchers in the Pacific Northwest also reported that crop residues left on the surface in reduced tillage systems appeared to contribute to a decrease in incidence of strawbreaker foot rot caused by the fungus *Pseudocercosporella herpotrichoides* (Veseth, 1986). The mechanism for this reduction was not clear but might have been related to reduced raindrop splash in the no-till system.

Hammel (1995) reported that after 10 years of continuous cropping, wheat yields in an Idaho experiment were lower under no-till tillage than minimum (chisel) or conventional (moldboard plow) tillage. It appeared that root function was reduced in both the reduced tillage systems possibly due to greater root disease pressure. However soil impedance and bulk density were also greater in the no-till system, so it was not clear what the relative importance of disease and soil compaction was. Growers in the Palouse region have not suffered yield loss under short-term no-till practices. It is not known whether the apparent disadvantages of continuous (annual) cropping with no-till reported for the Palouse would occur in a no-till summer fallow rotation under California climate conditions. The fungal diseases discussed here are not normally a significant problem in small grain production in California.

## Energy Use in No-Till Farming

A potential advantage of no-till over conventional tillage is a reduction in fuel use due to substitution of herbicide applications for cultivation of weeds and elimination of primary tillage for incorporation of harvest residues and preparation of the seedbed for the next crop.

Actual savings in fuel will depend on size of equipment, number of operations such as herbicide application and discing, etc. Examples of fuel use for typical field operations in both no-till and conventional tillage crop small grain farming are shown in Table 7. Fuel use values are based on information provided by dryland small grain growers during 1994 cost studies (Kearney et al., 1994a, 1994b; Klonsky et al., 1994a, 1994b).

The amount of energy used for planting may differ significantly between no-till and conventional tillage systems. Planting directly in untilled soil requires more energy. No-till planting often combines N fertilizer application and seeding in a single operation involving the use of separate fertilizer knives. A U.C. comparison of two no-till planters at three locations under untilled and tilled conditions was conducted in 1991. A planter with a "cross-slot" opener -- a large coulter with fertilizer blades mounted next to it -- required 51 to 118% more pulling force in untilled than in tilled ground. A second no-till drill with a double disc opener and separate fertilizer knives required 13 to 92% more pulling force on untilled ground (Sime et al., 1992).

A comparison of total energy inputs to no-till and conventional tillage systems is shown in Table 8. Energy values are based on data from the above-cited cost studies. The energy cost of weed management includes energy contained in the herbicides, energy in fuel used in ground or aerial application of herbicides, and energy sequestered in equipment. Weed control differences between the no-till and conventional tillage systems accounted for most of the difference in total energy inputs. No-till wheat and barley used 5 to 17 gal/acre of diesel less than the conventional systems, equivalent to 12 to 36% of the energy used to grow these crops. These figures refer to total system energy inputs and have been converted to diesel fuel equivlents for ease of comparison.

A more complete energy analysis including a discussion of the methods used to derive fuel equivalents is presented in Appendix E.

**Table 7. Examples of fuel use for equipment used in conventional and no-till dryland grain operations (data derived from sample cost studies, Kearney et al., 1994a, 1994b and Klonsky et al., 1994a, 1994b). For some operations, more than one example is shown.**

| Operation | Equipment Used | Diesel Fuel, gal/acre |
|---|---|---|
| Conventional till | | |
| Plow | 205 hp crawler + 8-bottom plow | 12.8 |
| Chisel plow | 360 hp 4wd tractor + 40-ft chisel plow | 6.1 |
| Disc/roll | 205 hp crawler + 21-ft disc + 21-ft ring roller | 6.5 |
| Cultivate | 280 hp 4wd tractor + 30-ft field cultivator | 2.5 |
| Plant | 205 hp crawler + 39-ft grain drill | 4.5 |
| Plant | 280 hp 4wd tractor + 30-ft grain drill | 4.7 |
| No-till | | |
| Apply fallow herbicide | 360 hp 4wd tractor + 1000-gal sprayer + 60-ft boom | 2.0 |
| Apply fallow herbicide | ATV + 110 gal sprayer + 30-ft boom | 0.24[a] |
| Plant/fertilize | 160 hp crawler + 13-ft no-till drill | 16.5 |
| Plant/fertilize | 360 hp 4wd tractor + 15-ft no-till drill | 17.2 |

[a]gasoline

**Table 8. Total input energy for no-till and conventional tillage wheat and barley systems. Data are from California sample cost studies (Klonsky et al., 1994a, 1994b and Kearney et al., 1994a, 1994b). Inputs include energy in fuel, machinery, labor, pesticides, and fertilizers and are converted to fossil fuel equivalents.**

| | No-till | | Conventional tillage | |
|---|---|---|---|---|
| Total input energy | Wheat | Barley | Wheat | Barley |
| Million BTU/acre | 5.3 | 6.1 | 8.3 | 6.9 |
| Diesel equivalent, gal/acre | 31.2 | 35.6 | 48.5 | 40.5 |

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# Appendices

## Appendix A. Highly Erodible Land, Conservation Tillage, and No-Till Acreage in California

In a 1985 report, the USDA Natural Resources Conservation Service estimated that about a quarter billion tons of soil are washed and blown from California's rural non-federal lands each year.

Soil erosion is harmful for two reasons: First if erosion occurs faster than the natural rate of soil formation, the productive capacity of that soil will decrease due to loss of nutrients and good tilth (i.e. desirable physical characteristics) found in the root zone. Secondly, eroded sediments, both mineral and organic matter, can degrade water quality of surface waters.

The rate at which soils form from the parent material is highly variable and dependent on several soil-forming factors. A typical annual rate of formation is about 5 ton/acre, equal to about one inch of soil in 30 years. This is known as the "T value", which is defined as the maximum annual rate of soil erosion that can take place without causing a decline in long-term productivity.

The NRCS classifies a soil as "highly erodible" if it has an erodibility index of eight or more. The erodibility index is determined by dividing the estimated potential rate of erosion due to wind or water (by sheet or rill erosion) by the "T value". A field is judged as highly erodible if a highly erodible soil makes up one-third or more of the field or more than 50 acres. The ASCS maintains a permanent record of all fields that have an HEL designation.

The calculation of the potential rate of erosion does not take into account management or conservation activities. The method of calculation is described in Appendix B.

It is estimated that approximately 950,000 acres of land in California meets this definition and is therefore classified as "highly erodible land" or HEL (Table A). Most of this is non-irrigated cropland, with slightly more than half occuring in the central California counties of San Luis Obispo, Kern, Fresno, and Monterey. In Yolo County in the Sacramento Valley, half of the 42,000 acres of HEL are covered by conservation compliance and half by Conservation Reserve Program contracts. Erosion rates before conservation practices were in place approached 20 tons/acre on some of the steeper fields, and averaged somewhere around 10 tons/acre annually. Erosion rates on conservation compliance land now average about 5 ton/acre and on CRP land about 1 ton/acre.(*Source: Runoff, p. 7, Summer 1994, newsletter of the Soil and Water Conservation Society, California Chapter, Woodland, CA)*

Conservation tillage is practiced on about one million acres of land in California (Table A). Of this, about 60% is accounted for by mulch-tilled winter cereals. Only about 14,000 acres of small grain no-till existed in California in 1994. Not all of the conservation tillage acreage is on Highly Erodible Land.

**Table A1. Acreage of Highly Erodible Land (HEL) and conservation tillage (all crops) in California, 1994. Source: Conservation Technology Information Center, West Lafayette, IN.**

| County | HEL | Cons. tillage | County | HEL | Cons. tillage |
|---|---|---|---|---|---|
| Alameda | 11,152 | 0 | Orange | 0 | 300 |
| Alpine | 40 | 0 | Placer | 13 | 500 |
| Amador | 0 | 780 | Plumas | 0 | 0 |
| Butte | 525 | 600 | Riverside | 37,339 | 51,100 |
| Calaveras | 0 | 0 | Sacramento | 0 | 19,620 |
| Colusa | 5,265 | 0 | San Benito | 8,921 | 4,500 |
| Contra Costa | 25,175 | 0 | San Bernardino | 3,301 | 1,320 |
| Del Norte | 0 | 0 | San Diego | 105 | 410 |
| El Dorado | 5 | 0 | San Francisco | 0 | 0 |
| Fresno | 54,977 | 241,950 | San Joaquin | 6,080 | 65,000 |
| Glenn | 25,877 | 800 | San Luis Obispo | 202,739 | 14,300 |
| Humboldt | 0 | 0 | San Mateo | 1,769 | 2,000 |
| Imperial | 110,300 | 116,150 | Santa Barbara | 1,237 | 0 |
| Inyo | 1,604 | 540 | Santa Clara | 507 | 0 |
| Kern | 213,471 | 149,225 | Santa Cruz | 116 | 0 |
| Kings | 10,813 | 85,000 | Shasta | 105 | 60 |
| Lake | 264 | 0 | Sierra | 0 | 0 |
| Lassen | 4,820 | 200 | Siskiyou | 33,558 | 700 |
| Los Angeles | 18,480 | 1,000 | Solano | 13,848 | 13,900 |
| Madera | 22,672 | 47,640 | Sonoma | 653 | 500 |
| Marin | 881 | 0 | Stanislaus | 11,806 | 62,600 |
| Mariposa | 0 | 0 | Sutter | 0 | 2,000 |
| Mendocino | 117 | 0 | Tehama | 18,265 | 0 |
| Merced | 10,213 | 69,100 | Trinity | 0 | 0 |
| Modoc | 2,521 | 6,500 | Tulare | 3,096 | 117,200 |
| Mono | 2,405 | 350 | Tuolumne | 0 | 0 |
| Monterey | 42,090 | 7,500 | Ventura | 1 | 0 |
| Napa | 104 | 0 | Yolo | 42,855 | 14,520 |
| Nevada | 0 | 50 | Yuba | 0 | 0 |
| | | | **TOTAL** | 950,049 | 1,097,915 |

## Appendix B. Calculation of Erosion Rate

The USDA Natural Resources Conservation Service makes two kinds of estimates of soil erosion: (1) Classification of soil mapping units as highly erodible (HEL) or potentially highly erodible; and (2) field-specific estimates of erosion potential for conservation compliance purposes. In the first case, management and conservation practices are not considered. In the second type of estimate, these are factored in.

To estimate potential soil loss in tons/acre per year due to sheet and rill erosion by water, the NRCS uses the Universal Soil Loss Equation (USLE), which includes factors for

(1) Run off and rainfall (R factor)
(2) Susceptibility of a particular soil to erosion (K factor)
(3) Combined effect of slope length and steepness (LS factor)
(4) Cover and management (C factor)
(5) Support practices, such as stripcropping (P factor).

For determination of whether an area should be classified as HEL, only the R, K, and LS factors are considered.

The quantitative effect of each of these factors has been determined by researchers in many separate experiments. Some of the information needed to estimate each of these factors can be obtained from the descriptions of soil mapping units contained in the county soil surveys. Other data must be obtained from field observations, for example length of slope.The predicted losses can be compared to a soil loss tolerance for the site. Factors considered in defining the tolerances include soil depth, physical properties and other characteristics affecting root development, gully prevention, on-field sediment problems, soil organic matter reduction and plant nutrient losses. Annual soil loss tolerances generally range from 2 to 5 ton/acre.

**Calculating Wind Erodibility:** Potential erodibility by wind is estimated by use of an equation containing a climate factor (C) for characterizing windspeed and surface soil moisture and a soil factor (I) that quantifies the susceptibility of the soil to wind erosion.

For more detailed information, contact the local NRCS office.

## Appendix C. Federal Conservation Programs

**Agricultural Conservation Program (ACP)**

The ACP is a cost-sharing program involving cooperation among growers, government agencies and other groups to solve soil, water and related pollution problems through cost-sharing on enduring conservation practices, including two that involve conservation tillage -- No-till systems (SL-15) and Reduced tillage systems (SL-14)

To qualify for cost-sharing, the soil has to be eroding over the calculated tolerance ("T" value -- see Appendix B), but the land does not have to be classified as HEL (Highly Erodible Land). The Consolidated Farm Services Agency (CFSA) will share 50-75% of the costs of the practice. The exact amount varies by county and practicer. For example, some no-till grain producers are receiving $15/acre through the ACP to support the cost of chem-fallowing. A grower cannot cost-share on the same field for more than three years.

The CFSA's share will not exceed $3,500 per participant per year unless there is a Pooling Agreement. A pooling agreement requires a pooling of resources between farms. Consult your local CFSA office for details.

**Conservation Compliance**

The conservation compliance provision of the Food Security Act of 1985 as amended by the Food, Agriculture, Conservation, and Trade Act (FACTA) of 1990 discourages the production of crops on highly erodible cropland where the land is not carefully protected from erosion. If you produce crops on such fields without an approved conservation system, you may lose your eligibility for certain USDA program benefits. Conservation compliance applies to all highly erodible land. HEL is land where the potential erodibility is more than eight times the rate at which the soil can maintain continued productivity, or in other words

The Conservation Reserve Program (CRP) enacted in December, 1985, encourages farmers to stop growing crops on highly erodible cropland and plant it to grass or trees through 10-year contracts with the USDA. The CFSA is the administering agency. Annual rental payments are

has an erodibility index of 8 or more. For a field to be considered highly erodible, one-third or more of it must be highly erodible, or the highly erodible area must be 50 acres or more. Employees of the Natural Resources Conservation Service (NRCS) determine if a field is highly erodible by consulting soil maps and by visiting the site.

If the land is classified as HEL, the farmer must develop and apply a conservation plan. The plan will help reduce soil loss to levels that are technically and economically achievable, and the farmer will retain eligibility for USDA farm program benefits. A second option is to plant permanent cover on fields. The land may be entered into the Conservation Reserve Program when sign-ups are held.

For land coming out of expired CRP contracts, producers must use an approved conservation system if the land is returned to crop production.

Conservation compliance as defined in FSA in 1985 and FACTA in 1990 affects several USDA programs involving small grain producers in California:

Price and income supports
Crop insurance
Conservation Reserve Program
Agricultural Conservation Program
Water Quality Incentives Program

Persons applying for USDA program benefits must certify annually to the CFSA that the FSA conservation plan is being actively applied to their highly erodible land fields as scheduled, and/or that the person is using an approved conservation plan. The person must notify CFSA and NRCS when land is purchased or rented. The CFSA will notify them of the existence of HEL on this land.

**Conservation Reserve Program**

made. The USDA also pays up to 50% of cost for establishing permanent vegetative cover on CRP land. CRP contracts have been approved for fields with two-thirds or more of the area classified as highly erodible.

For participating growers, CRP has several important features: Acreage bases were reduced by the ratio of cropland on the farm to acreage put into the program. Haying and grazing are not permitted during the contract period. However, an owner may charge for recreational access such as hunting.

As of May, 1994, California had 524 CRP contracts totaling 190,522 acres in 20 counties. San Luis Obispo has 242 of these contracts, and Monterey, Yolo, and Siskiyou counties account for 68 more. The first four CRP signups produced 300 contracts on 129,000 acres that will expire in 1996 and 1997.

# Appendix D. Sample Operating Costs to Produce No-till and Conventional-till Wheat and Barley Grain in California

**Table D1. Sample operating costs for dryland wheat, Yolo Co. (Kearney et al., 1994a and 1994b).**

| **A. NO-TILL** (Yield = 1,891 lb/acre) | Quantity/Acre | Unit | $/unit | $/acre |
|---|---|---|---|---|
| Wheat Seed - Serra | 100.00 | Lb | 0.12 | 12.00 |
| Fertilizer: | | | | |
| 16-20-0 | 150.00 | Lb | 0.10 | 15.00 |
| Aqua Ammonia | 50.00 | Lb | 0.193 | 9.65 |
| Herbicide: | | | | |
| Buctril | 1.60 | Pint | 9.74 | 15.58 |
| Hoelon 3 EC | 1.60 | Pint | 10.73 | 17.17 |
| Custom: Market Hauling | 0.95 | Ton | 8.00 | 7.60 |
| Labor (machine) | 0.80 | Hrs | 8.71 | 6.98 |
| Labor (non-machine) | 0.00 | Hrs | 0.00 | 0.00 |
| Fuel - Gas | 0.55 | Gal | 1.17 | 0.65 |
| Fuel - Diesel | 3.24 | Gal | 0.85 | 2.75 |
| Lube | | | | 0.51 |
| Machinery repair | | | | 14.48 |
| Interest on operating capital @ 7.89% | | | | 4.12 |
| **TOTAL OPERATING COSTS/ACRE** | | | | **106.50** |

| **B. CONVENTIONAL TILLAGE** (Yield = 2,940 lb/acre) | Quantity/acre | Unit | $/unit | $/acre |
|---|---|---|---|---|
| Wheat Seed - Serra | 100.00 | Lb | 0.12 | 12.00 |
| Fertilizer: | | | | |
| 11-52-0 | 65.00 | Lb | 0.134 | 8.71 |
| 21-0-0-24 | 200.00 | Lb | 0.069 | 13.80 |
| Custom: | | | | |
| Air Application - Fert. | 2.00 | Cwt | 3.85 | 7.70 |
| Air Application - Herb. | 1.00 | Acre | 7.50 | 7.50 |
| Market Hauling | 1.47 | Ton | 8.00 | 11.76 |
| Herbicide: | | | | |
| Buctril | 1.25 | Pint | 9.74 | 12.18 |
| Hoelon 3 EC | 1.00 | Pint | 10.73 | 10.73 |
| Labor (machine) | 1.61 | Hrs | 8.71 | 14.03 |
| Labor (non-machine) | 0.00 | Hrs | 0.00 | 0.00 |
| Fuel - Gas | 0.62 | Gal | 1.17 | 0.73 |
| Fuel - Diesel | 13.28 | Gal | 0.85 | 11.29 |
| Lube | | | | 1.80 |
| Machinery repair | | | | 14.53 |
| Interest on operating capital @ 7.89% | | | | 6.62 |
| **TOTAL OPERATING COSTS/ACRE** | | | | **133.37** |

**Table D2. Sample operating costs for dryland barley, Central Coast (Klonsky et al., 1994a and 1994b).**

| **A. NO-TILL** (Yield=2,000 lb/acre) | Quantity/Acre | Unit | $/unit | $/acre |
|---|---|---|---|---|
| Herbicide: | 1.75 | | | |
| Roundup | 1.00 | Pint | 6.83 | 11.95 |
| Weedar 64 | 0.17 | Pint | 2.07 | 2.07 |
| Glean DF | | Oz | 34.60 | 5.88 |
| Seed: | 80.00 | | | |
| Barley | | Lb | 0.12 | 9.60 |
| Fertilizer: | 60.00 | | | |
| Aqua Ammonia | | Lb | 0.193 | 11.58 |
| Custom: | 1.00 | | | |
| Air Application | 2.00 | Appl | 5.00 | 5.00 |
| Haul Grain | 0.67 | Ton | 2.00 | 10.00 |
| Labor (machine) | 0.00 | Hrs | 7.71 | 5.14 |
| Labor (non-machine) | 0.30 | Hrs | 0.00 | 0.00 |
| Fuel - Gas | 9.42 | Gal | 1.17 | 0.35 |
| Fuel - Diesel | | Gal | 0.85 | 8.01 |
| Lube | | | | 1.25 |
| Machinery repair | | | | 15.67 |
| Interest on operating capital @ 7.89% | | | | 4.96 |
| **TOTAL OPERATING COSTS/ACRE** | | | | **91.47** |

| **B. CONVENTIONAL TILLAGE** (Yield=2,000 lb/acre) | Quantity/acre | Unit | $/unit | $/acre |
|---|---|---|---|---|
| Barley Seed | 80.00 | Lb | 0.12 | 9.60 |
| Fertilizer: | | | | |
| Aqua Ammonia | 65.00 | Lb | 0.193 | 12.54 |
| Custom: | | | | |
| Air Application | 1.00 | Acre | 6.75 | 6.75 |
| Haul Grain | 2.00 | Ton | 2.00 | 10.00 |
| Herbicide: | | | | |
| Glean DF | 0.17 | Oz | 34.60 | 5.88 |
| Labor (machine) | 1.12 | Hrs | 7.71 | 8.61 |
| Labor (non-machine) | 0.00 | Hrs | 0.00 | 0.00 |
| Fuel - Gas | 0.20 | Gal | 1.17 | 0.23 |
| Fuel - Diesel | 16.04 | Gal | 0.85 | 13.63 |
| Lube | | | | 2.08 |
| Machinery repair | | | | 10.95 |
| Interest on operating capital @ 7.89% | | | | 4.49 |
| **TOTAL OPERATING COSTS/ACRE** | | | | **84.77** |

# Appendix E. Energy Use in Dryland Small Grain Production

A U.C. research project examined the farming practices of dryland barley and wheat growers along California's Central Coast and Yolo County to determine differences between conventional tillage and no-till grain production. Four cost studies and energy budgets were produced from this research (Kearney et al., 1994a; Kearney et al., 1994b; Klonsky et al., 1994a; Klonsky et al., 1994b). This appendix describes methods of energy analysis and results. Information in this appendix is quoted or paraphrased from an unpublished paper "Energy Use in Dryland Grain Production" (1994, K. Klonsky and P. Livingston, Dept. of Agric. Economics, Univ. of Calif., Davis CA 95616). In addition to the information presented below, the paper contains an analysis of the energy content of the harvested crop and a comparison of production energy inputs and grain energy content.

**Methodology**

Energy for crop production can be categorized in two ways -- that which is used directly by cultural practices, e.g. fuels, seed, and fertilizer, and energy which is sequestered in an input used in crop production such as the energy for materials and manufacturing of a tractor. By drawing an imaginary boundary around the farm and counting all the inputs that go across the boundary, total energy consumed in crop production.

**Materials:** Crop inputs are converted to energy by multiplying the quantity of input by an energy coefficient. This study uses coefficients for various production inputs that were calculated previously (Pimentel, 1980; Green, 1987; Mudahar and Hignett, 1987; Haney et al., 1992). Estimates were made using data provided from industry sources and researchers for production inputs which lacked published coefficients. The basic unit of energy used in this study is a British thermal unit (Btu), though other units such as joule (J) and kilo calorie (kcal) are interchangeable.

**Machinery:** Transforming equipment into kcal requires a list of equipment used by the farms and the weight of each (Doering, 1980). The weight of machinery is the basis for calculating the sequestered energy. Energy in machinery is found in the raw materials, manufacturing process, and repair parts and maintenance. These are referred to as embodied, fabrication, and repair parts energy, respectively. Both embodied and fabrication energy are determined by multiplying the machinery weight by the appropriate coefficient. Repair and maintenance energy are determined by using a percentage of the embodied and fabrication energy which is based on the category equipment is placed in. The total hours of equipment use are multiplied by the associated hourly energy coefficient for each piece of machinery. This result is the total equipment energy for that crop. All individual equipment energy values are summed and the resulting total is entered as equipment energy in the budget.

**Investments:** Calculations for energy sequestered in individual investments consist of an energy coefficient multiplied by either the weight, square-footage, acreage, or hours used for each of the investment(Doering, 1980; Mudahar and Hignett, 1987). Energy per acre for individual investments are summed under a single line item in the energy budget.

**Data Collection And Assumptions:** The energy inputs for four systems were analyzed: conventionally tilled wheat, no-till wheat, conventionally tilled barley, and no-till barley. Equipment and materials used in grain production were derived from interviews with cooperating growers concerning their operations for their cropping systems. Yields used in this study were based on the growers' observations for typical production years. Farm size, acreage in grain production, and investments (such as buildings, fuel tanks, grain storage facilities, and miscellaneous equipment) were also based on growers' farms.

Employing grower data, hypothetical farms were created using the Budget Planner© (BP©)computer program. The program simulates representative farms based on cultural practices, inputs, equipment, business overhead, and investments collected from the interviews. Cost of production studies (crop budgets) compiled with BP© were used to determine what production inputs (and associated quantities) were used in the energy budgets. Computer spreadsheets were constructed similar to cost budget reports to generate energy budgets (Tables E2-E5). The energy budgets were based on "Cost and returns per acre to produce..." tables from the crop budgets (Kearney et al., 1994a and 1994b; Klonsky et al., 1994a and 1994b). These budgets (crop and energy) include all inputs and application rates, fuel use, labor requirements, and investments. Assumptions and calculations for crop budgets are discussed in the four cost studies.

**Labor:** Accounting for labor in energy analysis has been the subject of much discussion. The focus has been on whether to assess labor as energy towards crop production or treat it as a separate input measured in time rather than energy units (Fluck, 1992). This study approaches labor as the latter, in terms of labor-hours per acre. Labor is calculated for each operation based on time involved. Both labor time and cost for operations involving machinery are 20% higher than the operation time. This is to account for the extra labor involved in equipment set up, moving, maintenance, work breaks, and repair. If machine and non-machine labor are used, the two are summed into one labor figure.

### Results

For both crops there is clearly a substitution of energy in weed management between the conventional to no-till; from mechanical energy (cultivation) to chemical energy (herbicides). Closer examination of the material inputs reveals that the difference between the tilled and no-till systems comes from the contrasting weed management strategies. Control of weeds in both no-till barley and wheat is accomplished at greater energy savings through the use of chemicals alone, though apparently, resulting in lower yields for the wheat. The inputs used for weed management considered for the barley comparison include the energy from herbicides, custom air application, and equipment and fuel used only for weed control practices. The conventional tilled barley system required more than double the amount of energy for weed management operations than no-till. Most of the energy used in weed control for the conventionally tilled barley went for fuel. The no-till system did expend more energy in herbicides than did the conventional tilled system. But, weed management programs could quickly change if herbicide resistance becomes established, if new weeds are not controlled by available herbicides, or if herbicides are removed from the market. Though fallowing is an effective weed management practice, it still requires energy through the use of herbicides and/or cultivation.

Another way to compare energy use is by converting Btu estimates to a gallons of fuel basis. The results indicate that savings can be realized in farming no-till versus conventionally tilled grains (Table E1). No-till wheat and barley could save the equivalent of 17 to 5 gallons of diesel per acre over conventionally tilled cropping systems. This is equal to a 12%-36% energy savings for growing wheat and barley.

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**Table E1. Total input energy and labor for no-till and conventional tillage dryland grain production.**

| System | Yield lb/ac | Input energy 1000 Btu/acre | Equivalent gal diesel/acre[a] | Labor hrs/acre |
|---|---|---|---|---|
| Wheat - Tilled | 2,940 | 8,306 | 48.5 | 1.61 |
| Wheat - No-till | 2,891 | 5,344 | 31.2 | 0.80 |
| Barley - Tilled | 2,000 | 6,948 | 40.5 | 1.12 |
| Barley - No-till | 2,000 | 6,104 | 35.6 | 0.67 |

[a]One gallon of diesel fuel contains 171,405 Btu including material and production energy (Cervinka, 1980; Pimentel, 1992)

**Table E2. Energy requirements for dryland wheat production, Yolo Co.**

| Operating input | Quantity/acre | Unit | Btu/acre |
|---|---|---|---|
| **CONVENTIONAL TILLAGE** | | | |
| **Wheat seed** | 100 | Lb | 1,193,081 |
| **Fertilizer** | | | |
| 0-45-0 | 65 | Lb | 106,806 |
| 21-0-0-24 | 570 | Lb | 2,993,063 |
| **Herbicide** | | | |
| Buctril | 0.16 | Gal | 56,152 |
| Hoelon 3EC | 0.13 | Gal | 67,383 |
| **Custom/Contract/Rental** | | | |
| Air Application | 3 | Applic. | 87,576 |
| Haul | 2940 | Lb | 1,176,221 |
| **Fuel** | | | |
| Gasoline | 0.62 | Gal | 94,127 |
| Diesel | 13.28 | Gal | 2,276,262 |
| **Machinery: Total Equipment** | | | 130,487 |
| **Total Investments** | | | 124,965 |
| **Labor** | 1.61 | Hours | |
| **TOTAL INPUT** | | Btu | 8,306,123 |

| | | | |
|---|---|---|---|
| **NO-TILL** | | | |
| **Wheat seed** | 100 | Lb | 1,193,081 |
| **Fertilizer** | | | |
| Aqua ammonia | 50 | Lb N | 1,650,310 |
| 16-20-0 | 150 | Lb | 775,741 |
| **Herbicide** | | | |
| Buctril | 0.20 | Gal | 71,875 |
| Hoelon 3EC | 0.20 | Gal | 107,812 |
| **Custom haul** | 1891 | Lb | 756,812 |
| **Fuel** | | | |
| Gasoline | 0.55 | Gal | 83,500 |
| Diesel | 3.24 | Gal | 555,353 |
| **Machinery: Total Equipment** | | | 51,051 |
| **Total Investments** | | | 98,704 |
| **Total labor** | 0.80 | Hours | |
| **TOTAL INPUT** | | Btu | 11,206,895 |

**Table E3. Energy requirements for dryland barley production, Central Coast.**

| Operating Input | Quantity/acre | Unit | Btu/acre |
|---|---|---|---|
| **CONVENTIONAL TILLAGE** | | | |
| **Barley seed** | 80 | Lb | 1,053,531 |
| **Fertilizer: Aqua ammonia** | 65 | Lb N | 2,145,403 |
| **Herbicide: Glean DF** | 0.01 | Lb | 1,384 |
| **Custom/Contract/Rental** | | | |
| Air Application | 1 | Ac | 29,192 |
| Haul | 2000 | Lb | 800,150 |
| **Fuel** | | | |
| Gasoline | 0.2 | Gal | 30,364 |
| Diesel | 16.04 | Gal | 2,749,340 |
| **Machinery: Total equipment** | | | 96,914 |
| **Total Investments** | | | 42,021 |
| **Total labor** | 1.12 | Hours | |
| **TOTAL INPUT** | | Btu | 6,948,299 |

| | | | |
|---|---|---|---|
| **NO-TILL** | | | |
| **Barley seed** | 80 | Lb | 1,053,531 |
| **Fertilizer: Aqua ammonia** | 60 | Lb N | 1,980,372 |
| **Herbicide** | | | |
| Roundup | 0.22 | Gal | 432,531 |
| Weedar 64 | 0.13 | Gal | 98,876 |
| Glean DF | 0.01 | Lb | 1,337 |
| **Custom/Contract/Rental** | | | |
| Air application | 1 | Applic. | 29,192 |
| Haul | 2000 | Lb | 800,150 |
| **Fuel** | | | |
| Gasoline | 0.3 | Gal | 45,545 |
| Diesel | 9.4 | Gal | 1,614,637 |
| **Machinery: Total Equipment** | | | 5,680 |
| **Total Investment** | | | 42,297 |
| **Total Labor** | 0.67 | Hours | |
| **TOTAL INPUT** | | Btu | 6,104,149 |